DEVELOPMENT OF SELF-COMPACTING AND LOW HEAT HIGH PERFORMANCE CONCRETE

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ABSTRACT

The purpose of this study is to develop the low heat, highly flowable and durable concrete. It can be cast into form without any compaction. In order to reduce the heat of hydration, the limestone powder and urea are used. In this paper, the mix proportioning of low heat highly flowable concrete and the properties of this concrete, especially, the effect of urea on slump, slump flow, flowability, temperature, strength, drying shrinkage, carbonation resistance and resistance to chemical attack are discussed. The result show that urea is the effective as concrete admixture not only for reduction of heat of hydration in concrete, but for improvement of flowability and durability of concrete. It is also clarified that drying shrinkage is greatly improved for concrete in which urea has been used.

KEYWORDS

Self-compacting; Low heat; Slump flow; Strength; Durability; Shrinkage strain; Urea

INTRODUCTION

The purpose of this study is to develop the concrete which has the specific characters of high flowability, low heat of hydration and high durability. The high flowability of this concrete is to place the concrete into form without any compaction. The high flowability gives the concrete self-setting property. In order to make high flowability, the slump and slump flow of this concrete should be more than 250 mm and between 600 mm and 700 mm, respectively [Sakata et al. (1995)]. Generally, the powder content of highly flowable concrete is larger than that of normal concrete [Ozawa et al. (1989)]. When urea is mixed with concrete, the temperature of that concrete is reduced by the endothermic reaction between urea and water. By using this property, it is possible to reduce the temperature of concrete at both casting stage and during later hydration process [Sakata et al. (1988)]. This is advantageous in mass concrete constructions and when concrete is cast under high ambient temperature like in summer or in hot tropical areas.

In this study, the limestone powder and urea are used as the admixture minerals to reduce the heat of hydration and to give this concrete viscosity. Limestone powder is a well known low reactive materials. By replacing a part of cement by limestone powder, it can be reduced the maximum temperature of concrete without changing the powder content which is the important factor of mixture proportion of self-compacting high performance concrete. In this paper, the properties of the self-compacting high performance concrete incorporating urea, especially the effect of urea on slump, slump flow, flowability, temperature, strength, drying shrinkage, carbonation resistance and resistance to chemical attack are discussed.

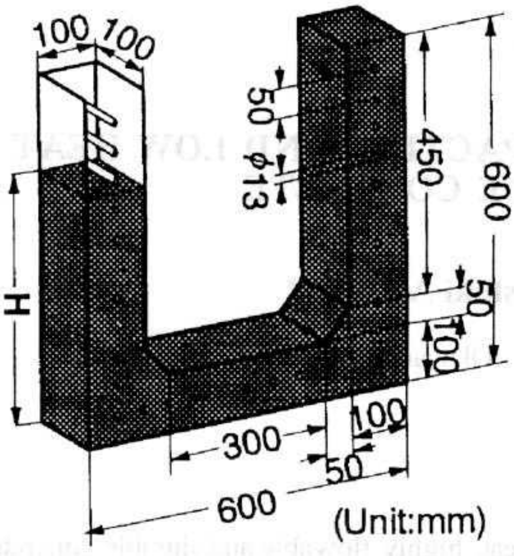


Fig.1. U-shaped apparatus

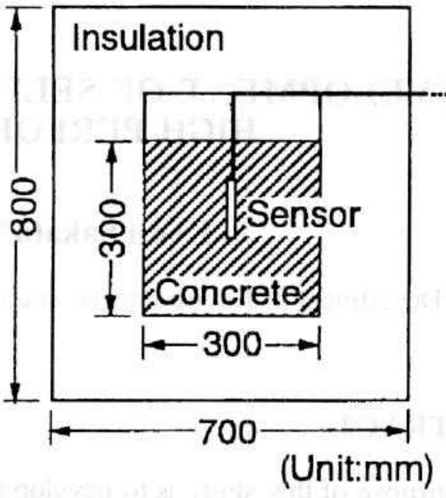


Fig.2. Semi-adiabatic apparatus

Table 1. Mix proportions of concrete for durability test

Type of concrete	W/C (%)	s/a (%)	Unit weight per volume (kg/m^3)							
			W	C	Lf	Urea	Sand	Gravel	S.P.	S.R.
Normal	40.0	46.8	155	388	0	0	857	1027	0.00	0.0
	60.0	47.0	180	300	0	0	865	1027	0.00	0.0
	80.0	46.7	200	250	0	0	854	1027	0.00	0.0
SCC	40.0	42.5	155	388	179	0	706	1006	9.12	1.5
	60.0	42.5	180	300	187	0	706	1006	7.05	7.0
	80.0	42.5	200	250	176	0	706	1006	5.88	10.0
SCC with urea	50.0	42.5	150	300	184	53	696	992	7.05	7.0
	40.0	42.5	120	300	182	107	686	977	7.05	7.0
	72.8	42.5	182	250	175	27	704	1003	5.88	10.0
	58.4	42.5	146	250	174	80	700	997	5.88	10.0

SCC: Self-compacting high performance concrete
SCC with urea: Self-compacting and low heat high performance concrete
Lf: Limestone powder, S.P.: Superplasticizer, S.R.: Segregation reducing agent

OUTLINE OF EXPERIMENT

Type of cement used was normal portland cement (specific gravity : 3.15). The fine aggregate was river sand (specific gravity : 2.61, water absorption : 1.61%, FM : 2.51). The coarse aggregate was crushed stone (specific gravity : 2.75, water absorption : 0.74%, FM : 6.47). The specific gravity of limestone powder was 2.73 and its specific surface was 2,800 cm^2/g by Blaine. The specific gravity of urea was 1.34. The type of superplasticizer was naphthalene formaldehyde condensate. The type of segregation reducing agent was acrylamide admixture. The flowability of concrete was measured by the U-shaped apparatus shown in Fig.1. Concrete is poured on one side of the apparatus and due to flowability it rises by its own weight to the opposite side. The distance "H" from the bottom corner of the side is measured. When concrete can rise in the other side, the distance "H" is considered positive, but when concrete can not rise in the other side, the distance "H" is considered negative. The heat of hydration process and rising temperature of concrete was measured by a semi-adiabatic apparatus shown in Fig.2. The data of concrete temperature was recorded over one week. The setting and hardening process was measured by using a proctor needle

Table 2. Mix proportions of concrete

Unit weight per volume(kg/m^3)						Admixture(kg/m^3)	
W	C	Lf	U	S	G	S.P.	S.R.
162	300	182	48(36)	688	980	7.05	7.0
153		185		697	993		
144		187		706	1006		
144	300	177	96(72)	670	955	7.05	7.0
126		182		688	980		
108		187		706	1006		
113	300	176	144(108)	665	948	7.05	7.0
99		180		679	967		
86		183		692	987		

S.P. :Superplasticizer
S.R. :Segregation reducing agent
( ) :Volume(litre)

Table 3. Mix proportions of concrete

Unit weight per volume(kg/m^3)						Admixture(kg/m^3)	
W	C	Lf	U	S	G	S.P.	S.R.
155	388	179	0	706	1006	9.12	1.5
143		177	27(20)	698	995		
131		175	53(40)	690	983		
119		173	80(60)	682	972		
107		171	107(80)	674	960		
180	300	187	0	706	1006	7.05	7.0
165		186	27(20)	701	999		
150		184	53(40)	696	992		
135		183	80(60)	691	985		
120		182	107(80)	686	977		
200	250	176	0	706	1006	5.88	10.0
182		175	27(20)	704	1003		
164		175	53(40)	702	1000		
146		174	80(60)	700	997		
128		174	107(80)	698	995		

S.P. :Superplasticizer
S.R. :Segregation reducing agent
( ) :Volume(litre)

penetration instrument in accordance with Japanese Industrial Standard. The 10x20cm cylinders were used for the determination of compressive strength. The drying shrinkage was measured on the rectangular specimens of size 10x10x40cm. After curing in water for 28 days, the specimens were transferred to the room with constant temperature and relative humidity of 19±1℃ and 68±7%, respectively. Carbonation was measured using ϕ 10x20cm cylinders. The specimens were put in the chamber where the concentration of CO_2 was kept constant at 20%, relative humidity at 60% and temperature at 30℃, after initial storage in water for 27 days and then in dry air for one day. Sulfate resistance was measured in 10cmx10cmx40cm prism specimen. The specimens were cyclically exposed to 5% Na_2SO_4 solution and air every alternate week. Resistance to freezing and thawing was measured in ϕ10x20cm cylinder specimen. The specimens were cyclically kept in water, -30℃ room and 100℃ room every three weeks. The mix proportions of concrete for durablity test is shown in Table 1.

RESULTS AND DISCUSSION

Slump flow and flowability

Fig.3 shows the optimum water replacement ratio in the case of cement content is $300kg/m^3$. Table 2 shows the mix proportions of the concrete. As shown in this table, the ratio of limestone powder content, sand content and gravel content are constant. As is evident from Fig. 3, the slump flow of concrete is between 60 and 70 cm when the ratio of urea is 0.75. Other levels of cement content, which are 388 kg/m^3 and 250 kg/m^3, were also investigated. The optimum water replacement ratios of concrete with cement content of $388kg/m^3$ and 250 kg/m^3 are 0.6 and 0.9, respectively.

Fig. 4 shows the flowability of concrete measured by U-shaped apparatus. When the value of "H" is positive, it is considered that the flowability of concrete is good. These results were obtained using the concrete shown in Table 3. The bottom curve shows the flowability of concrete with no urea. From this figure, it can be observed that the flowability of concrete is influenced by urea plus water content. When urea and water content is less than 200 kg/m^3, the flowability of concrete increases in spite of cement content as the urea and water content increases. When the cement content is $250kg/m^3$, the change of flowability is very small even if urea plus water content is varied.

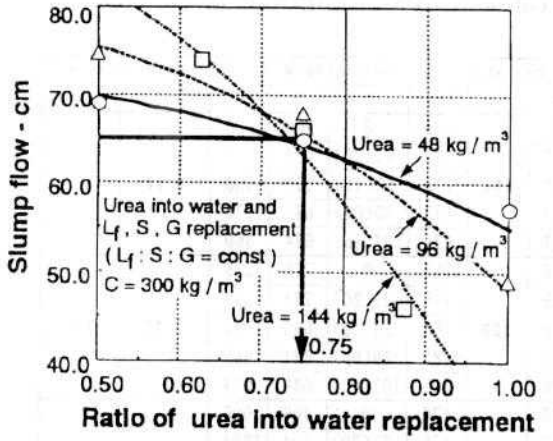


Fig.3. Slump flow of concrete

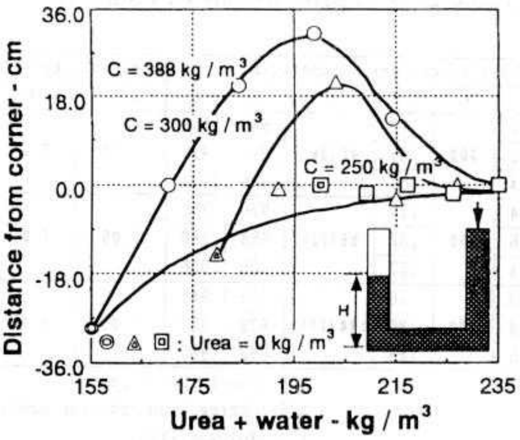


Fig.4. Flowability of concrete

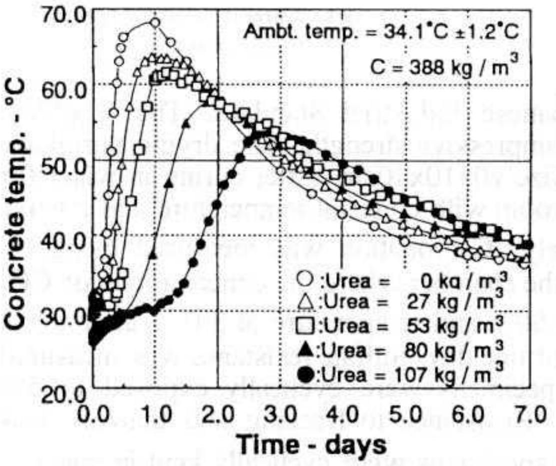


Fig.5. Temperature of concrete

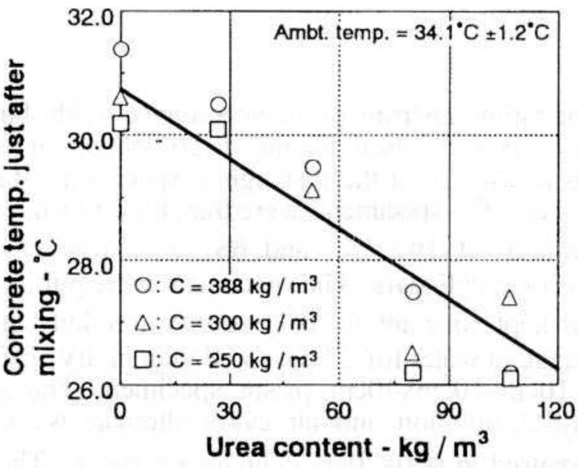
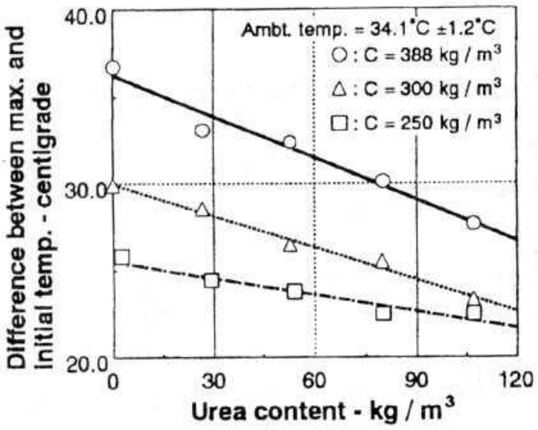


Fig.6. Temperature of concrete just after mixing

Temperature of concrete

Fig. 5 shows the influence of urea on concrete temperature. The cement content of concrete is 388 kg/m^3 as shown in the figure. From this figure, it is clear that both the concrete temperature just after mixing and the maximum concrete temperature are reduced by mixing urea. Furthermore, the time to reach the maximum temperature is delayed by the effect of urea. In the early stage of hydration, concrete temperature is affected by urea but in the later stage of hydration, the concrete temperature is almost same, regardless of the urea content. From this, it is considered that urea may somehow react with cement during hydration process which results to slowing down of the rising temperature of concrete. It has been recognized that other levels of cement content show similar results. Fig. 6 shows the temperature of concrete just after mixing with various urea content. It is observed that the concrete temperature just after mixing is decreased by endothermic reaction between urea and water. The drop of temperature of concrete up to 5 ℃ is observed when higher amount of urea is used. The decreasing temperature is not affected by cement content. Fig. 7 shows the differences between maximum and initial temperatures of concrete with different cement content. It is evident that the effect of urea is comparatively large when cement content is high. The difference between maximum and initial temperature of concrete is decreased linearly with the increase of urea content.



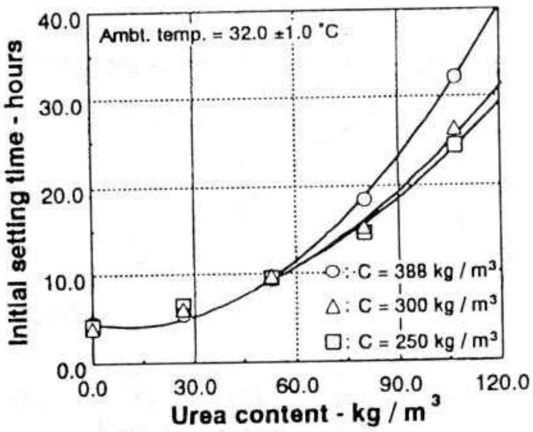
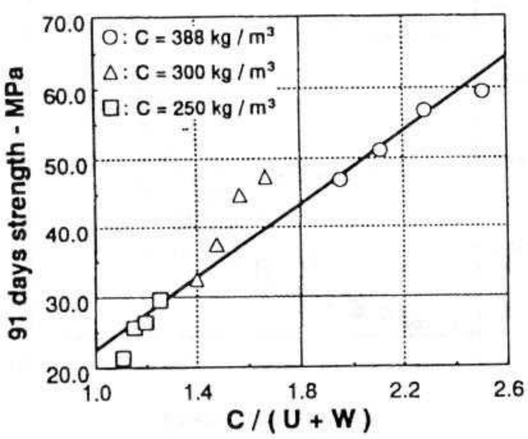


Fig.7. Difference between maximum and initial temp. Fig.8. Initial setting time



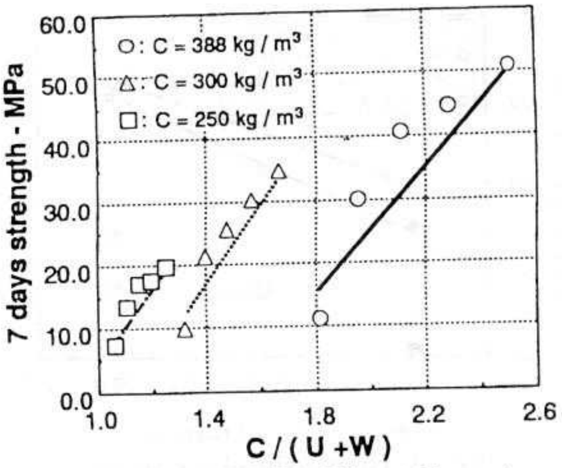


Fig.9. Effect of C/(U+W) on 91days strength Fig.10. Effect of C/(U+W) on 7days strength

Setting time of concrete

Fig. 8 shows the initial setting time of concrete as the amount of urea varied. When the amount of urea in concrete increases, initial setting time increases. It is considered that urea somehow reacts with parts of cement products during hydration process and thus slows the setting process of concrete. Further research is needed to explain this phenomenon.

Strength

Fig. 9 shows that the linear relationship between the 91 days strength of concrete and cement to urea plus water ratio. From this figure, it is clear that the effect of urea content on 91 days strength of concrete is same as that of water content. Fig. 10 shows the 7 days strength of concrete represented by the cement to urea plus water ratio. In this figure, the linear relationship can not be confirmed. Fig. 11 shows the 7 days strength of concrete represented by the urea plus water content. The relation between 7 days strength of concrete and the urea plus water content can be represented by a curve irrespective of cement content. It is clear that this relation is established at young age of concrete and not at the age of 91 days as shown in Fig. 12. These results mean that the effect of urea on concrete strength is dependent on the concrete age.

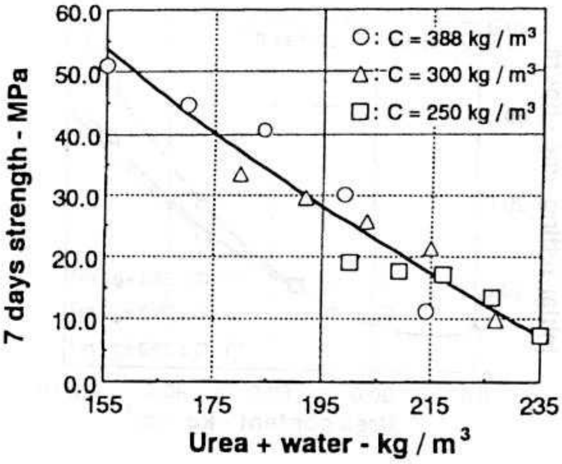


Fig.11. Effect of (U+W) on 7days strength

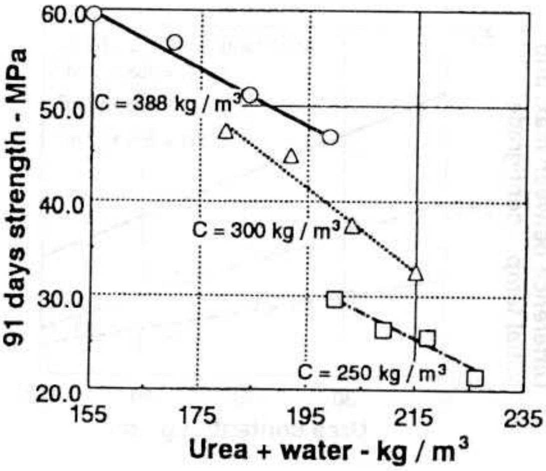


Fig.12. Effect of (U+W) on 91days strength

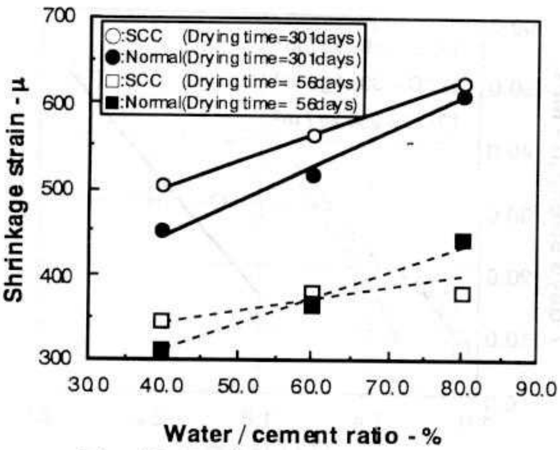


Fig.13. Drying shrinkage strain

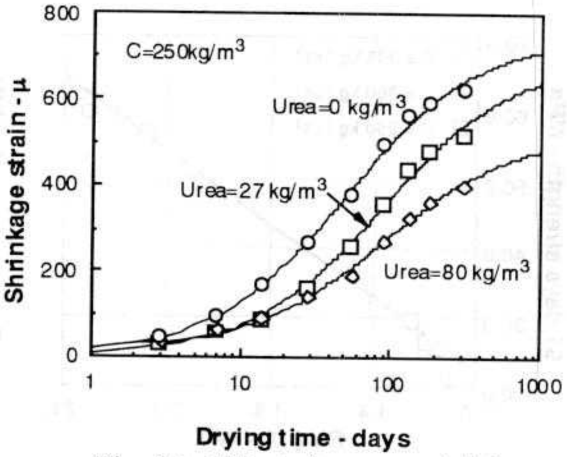


Fig. 14. Effect of urea on shrinkage

Drying shrinkage strain

Fig.13 shows the comparison of drying shrinkage strain between self-compacting high performance concrete and normal concrete. The difference of drying shrinkage strain of each concrete is not so big between the drying time of 56days and 301days. The drying shrinkage strain of each concrete is increased with water cement ratio. It is clear that the effect of limestone powder on the drying shrinkage strain is not significant. The drying shrinkage strain of self-compacting high performance concrete with different amount of urea is shown in Fig.14. The cement content of each concrete is 250 kg/m³. As evident from this figure, the shrinkage strain is decreased with high urea content. Since urea is replaced with a part of water content without the change of cement content in order to satisfy the characteristic of self-compacting high performance concrete, the water cement ratio becomes smaller and urea seems to reduce the shrinkage strain.

Carbonation

Fig.15 shows the comparison of carbonated thickness between self-compacting high performance concrete and normal concrete. The difference of carbonated thickness for each concrete is not so big between the drying time of 28 days and 91 days. In ordinary concrete,

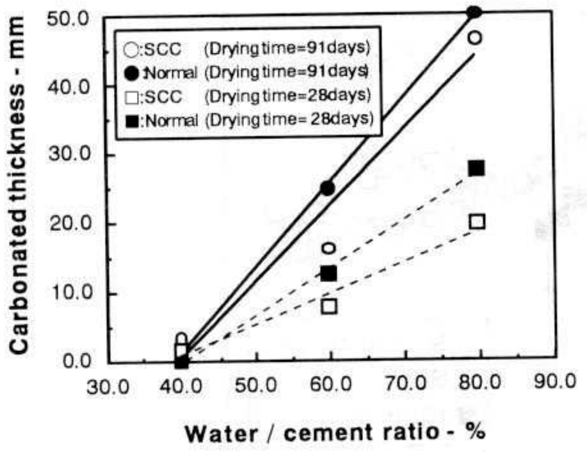


Fig.15. Carbonated thickness

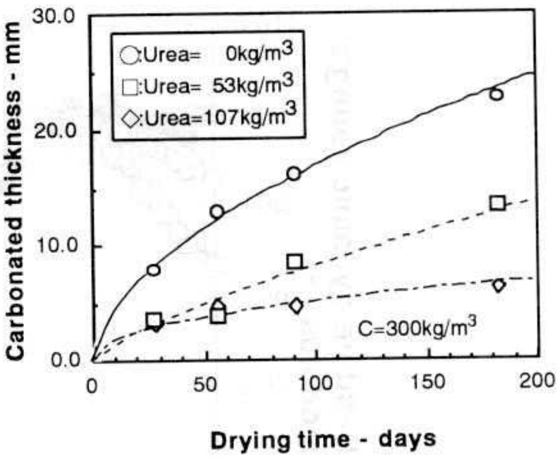


Fig. 16. Effect of urea on shrinkage

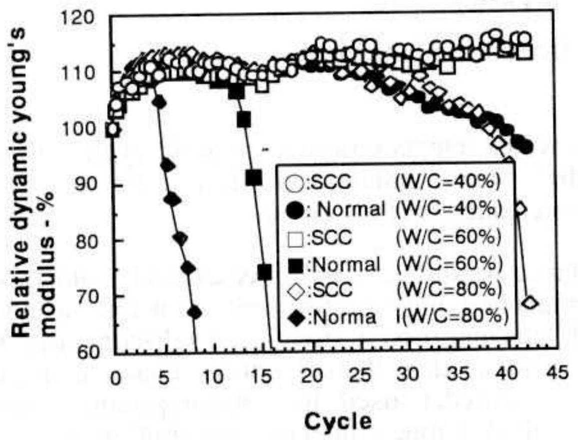


Fig.17. Resistance to sulfate attack

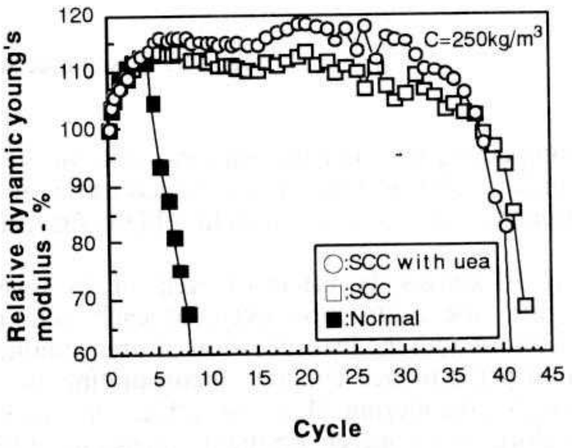


Fig. 18. Effect of urea on sulfate resistance

it is said that the carbonation starts after the concrete is dried. As mentioned in the previous section, the drying shrinkage strain of self-compacting high performance concrete is almost equal to that of normal concrete. Therefore, the difference of carbonation of each concrete seems to be quite small.

The carbonated thickness of self-compacting high performance concrete with different amount of urea is shown in Fig.16. The cement content of each concrete is 300 kg/m^3. As evident from this figure, the carbonated thickness decreases with urea content. It is considered that the concrete incorporating urea may be so dense that carbonation slows down.

Resistance to sulfate attack

Fig.17 shows the relative dynamic Young's modulus of the self-compacting high performance concrete and normal concrete subjected to sulfate attack. The normal concretes with 80%, 60% and 40% water cement ratio are completely destroyed after 8, 15 and 42 cycles, respectively. Whereas, the self-compacting high performance concrete, whose water cement ratio is 40% and 60%, have not been destroyed yet. The destruction of the self-compacting high performance concrete of 80% water cement ratio occurs at 42 cycles. It is almost same as that of normal concrete of 40% water cement ratio. It is clear that the durability of the self-compacting high performance concrete is improved.

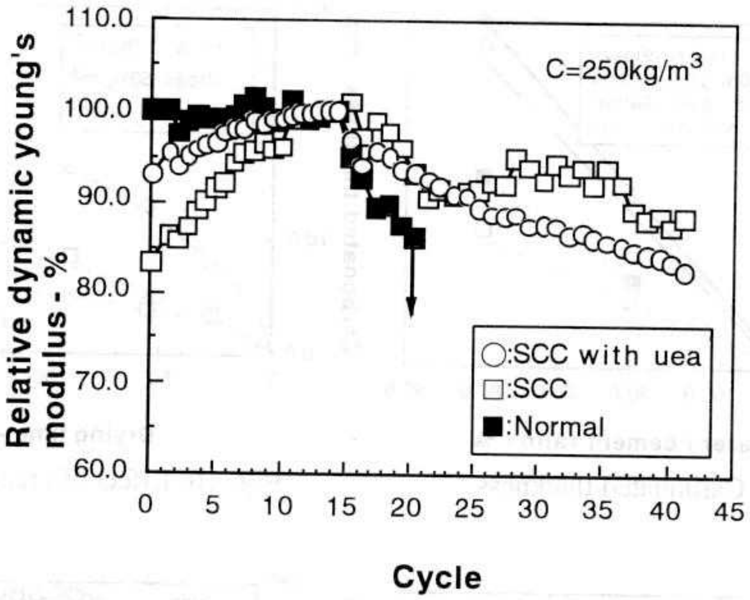


Fig. 19. Resistance to freezing and thawing

compacting high performance concrete of 80% water cement ratio occurs at 42 cycles. It is almost same as that of normal concrete of 40% water cement ratio. It is clear that the durability of the self-compacting high performance concrete is improved.

Fig.18 shows the effect of urea on the resistance to sulfate attack. As evident from this figure, the destruction cycle of each self-compacting high performance concrete is not different with the incorporation of urea although the compressive strength of self-compacting high performance concrete incorporating urea is lower than that of normal concrete. It is worth considering that the effect of limestone powder used in self-compacting high performance concrete on the resistance to sulfate attack is much bigger than that of urea.

Resistance to freezing and thawing

Fig.19 shows the resistance to freezing and thawing of normal concrete and self- compacting high performance concretes. Except for the normal concrete of 80% water cement ratio, no other concrete shown in Table 1 has broken down at 45 cycles, that is, at 945 days after the start of test. The relative dynamic Young's modulus of self-compacting high performance concrete shown in Fig. 9 decreases with each cycle. However, both concretes have not broken down yet. Although the actual breaking point of self-compacting high performance concrete can not be predicted, it is possible to say that the resistance to freezing and thawing of self-compacting high performance concrete is twice as good as that of normal concrete at least. The effect of urea on the resistance to freezing and thawing is quite small.

CONCLUSION

It was observed that urea reduce the temperature of concrete, and also enhanced the durability of concrete. The drying shrinkage strain and carbonated thickness of self-compacting high performance concrete are not different from that of normal concrete. It was, however, confirmed that the drying shrinkage strain and carbonated thickness are reduced when urea is incorporated in concrete. The resistance to sulfate attack and the resistance to freezing and thawing of self-compacting high performance concrete are much enhanced in comparison to that of normal concrete. The resistance to sulfate attack and the resistance to freezing and thawing of the self-compacting high performance concrete with urea is almost same as that of the self-compacting high performance concrete without urea, although the strength of the self-compacting high performance concrete with urea is lower than that of normal concrete. It can be expected that urea is useful admixture for low heat and self-compacting high performance concrete.

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